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SIMULATION OF HYSPLIT OF AIR POLLUTION IMPACT TOWARDS AGRICULTURAL GROWTH IN KEDAH DURING SOUTHWEST MONSOON SEASON IN 2019

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Abstract: Air pollution has been a significant problem in Malaysia and has a substantial impact on agricultural production. Particulate matter 10 (PM_{10}) is one of the major pollutants released by industries where it affects agricultural production by disrupting the photosynthesis process and the plant growth. In Malaysia, Kedah as the second largest producer of paddy and rice has four monitoring stations only to analyse the air quality. The lack of air monitoring stations around the state has put agricultural areas at elevated risk of being affected by air pollutants. Hence this research aims to simulate a backward trajectory HYSPLIT simulation from the air monitoring station to identify the source of PM_{10} emission coordinate and to conduct a forward concentration simulation to analyse the agricultural area affected by the pollutants. A starting date, meteorological data file, total runtime of simulation and coordinates of the monitoring stations during southwest monsoon season in 2019 were used as input for backward trajectory simulation while the obtained source emission coordinate was used as the input for forward concentration simulation. The result from the backward trajectory simulation shows that the source of emission coordinate was within Bayan Lepas after analysing every potential intersection on the map and the industries surrounding it. As revealed in the forward concentration simulation result, there were six agricultural areas exposed to an air pollutant concentration level that are low and moderate. It can be concluded that these exposed agricultural areas are within the safe limit.

Keywords: HYSPLIT; air monitoring station; Kedah; air pollution; particulate matter 10

1. Introduction

Air pollution can be described as the contamination of the air, whether it originates from the outside or from within. Air pollution occurs when air is contaminated with natural and anthropogenic pollutants (Zizi *et al.*, 2018). Natural air pollution is caused by volcanic emissions and natural fires. These generate a natural background concentration that changes according to weather conditions or local sources. On the other hand, anthropogenic pollutants are caused by physical, biological, and chemical entities such as harmful gases, dust, and smoke caused by human daily activities.

Typically, air contaminants have a negative impact on agricultural growth, either directly or indirectly by altering soil pH or through toxic effects. There are four types of air pollutants that cause severe consequences to plant growth which are sulphur dioxide (SO_2), nitrogen oxide (NO_x), ozone (O_3) and particulate matter (PM). The deposition of PM covers the leaf blade, decreases light transmission, and obstructs stomatal openings. These barriers inhibit photosynthesis, resulting in a precipitous fall in photosynthesis and growth. In contrast, tree leaves have a role in holding PM, although they are significantly more affected when dry depositions increase (Jyothi and Jaya, 2010).

Furthermore, NO_x dissolved in the cells produces nitrite ions, which enter the nitrogen metabolism as if they were absorbed through the roots. In some instances, exposure to pollutant gases, like SO_2, promotes stomatal closure, which protects the leaf from further pollutant entrance but inhibits the whole photosynthesis process. As for O_3, it is considered as a reactive gas. It binds to plasma membranes and modifies metabolism. Consequently, stomatal apertures are inadequately regulated, and chloroplast thylakoid membranes are damaged. Pollutants change the physiology and metabolism of plants due to their oxidising potential. To survive, plant species respond differently to environmental stimuli. The responses of plants to air pollutants depend on the nature, duration, and intensity of the pollutants (Kulshrestha and Saxena, 2016).

A study conducted by Kurnaz and Demir (2022) stated that particulate matter 10 (PM_{10}) and SO_2 pollutants give negative impact to the environmental compared to other air pollutants. Although the NO_x and O_3 pollutants lower the plant metabolism, the photosynthesis on the plant can still occur regardless of the low photosynthesis rate. As for the SO_2, the major sources come from volcanoes and burning of coal and fuel from power plant. In this study, only the

PM was selected as the pollutant because the fine particulate matter may physically damage the plant surface and change the plant's nutrient. The PM_{10} also may carry heavy metals or toxic substances that can be deposited on plant surfaces or absorbed by the roots. This can disrupt nutrient uptake and lead to nutrient imbalances, negatively impacting plant growth and development.

Air quality monitoring stations, also known as air pollution monitoring stations, are constructed at specific locations to monitor the concentration of air pollutants at various times of the day. These concentrations are expressed in terms of Air Quality Index (AQI). The term Air Pollution Index (API) is primarily used in Asian Countries such as Malaysia while AQI is used in United States and several other countries. The objective of establishing API is to assist the public in understanding how much the local air quality is affecting human health and how this has an impact on their daily lives. **Table 1** displays the impact on health and health advice at each API stage.

Table 1. Impact on Health and Health Advice for Each Stage (Department of Environment, 2019)

API	Status	Health Effect	Health Advice
0 - 50	Good	Low pollution with no negative health consequences.	Public outdoor activities are permitted without limitation.
51 - 100	Moderate	Moderate pollution with no harmful effects on health.	Public outdoor activities are permitted without limitation.
101 - 200	Unhealthy	Affects the health of the elderly, pregnant women, children, and those who have heart and lung diseases.	The high-risk group is limited to outdoor activities.
201 - 300	Very Unhealthy	People with lung and heart diseases will have a tolerance to physical activity which will worsen their health.	It is recommended that the elderly and those at risk stay indoors and limit their physical activities.
> 300	Hazardous	High-risk individuals and the public are at risk.	It is prohibited for the elderly and those at risk to go out and the public is recommended to limit outdoor activity.
> 500	Emergency	High-risk individuals and the public are at risk.	The public is instructed to obey National Security Council orders and pay attention to media announcements.

The API stage is not only affecting the human health but also the plant growth. Low API values are generally safe for human health as well as favourable for plant growth. The air quality at low API values is generally good indicating minimum particulate matters in the air. The possibility of the plant to experience adverse effect is also low due to the low level of PM emissions at this stage. In contrast, the high API value portrays the unhealthy air quality indicating high level of particulate matter that can have negative effects on both human health and plant growth.

Data on air pollutants from monitoring stations that are presented in numerical or literal form cannot well present a large area. Additionally, there is no geographic information included in the numerical form of data on air pollutants. Constructing more monitoring stations is another way to obtain more accurate data for a large area.

However, constructing a new monitoring station demands high capital. According to Alam Sekitar Malaysia (ASMA), an air monitoring station can only provide information for a 15 km radius and costs around one million (Ibrahim *et al.*, 2012). In other words, larger states require more monitoring stations to measure air pollution concentration and require a large amount of capital. Moreover, monitoring stations are only able to provide air quality status at specific times of certain locations only without giving detailed guidelines on how to identify the source of emission that causes the decline in air quality.

Rice production is one of the crucial sectors of agriculture in Malaysia and rice is considered the staple food of the country. The role of rice production does not only contribute to Malaysia's economy, but it can be seen as providing food security for the country as well. In Malaysia, eight major paddy granary states can be considered the main rice producers and Kedah is one of them. Kedah is Malaysia's eighth-largest state with 518,000 hectares of land and it is the largest rice producer in the nation. From 518,000 hectares of land, 112,000 hectares are utilised for rice cultivation (Alzubaidi *et al.*, 2016). However, Kedah has only four monitoring stations whereby these stations cannot represent or provide full coverage of the 112,000 hectares of paddy fields to provide the air pollution concentration. This information clearly indicates that there is absence of data related to air pollutant concentration on agricultural areas that are not covered by the monitoring station and there are chances that these areas could be exposed to air pollutants.

Hence, an air quality modelling simulation can be utilized to carry out what a monitoring station cannot provide, which providing a full coverage of the location to measure the concentration of the air pollutant and identify the areas exposed to air pollution. Furthermore, air quality models can be used to identify the source of emission so that appropriate measures can be taken to reduce the emission if its severe.

A backward trajectory simulation was conducted with inputs such as starting date, meteorological data file, total runtime of simulation and coordinates of the monitoring stations to obtain the source of emission coordinates. The coordinates of the source of emission were then used to run a forward concentration simulation to obtain a concentration map that was further converted to google earth map format. The google earth map obtained was used to analyse the agricultural areas exposed to air pollutant**.**

2. Research Area and Methodology

2.1. Air Quality Model

This study uses an air quality modelling Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT). HYSPLIT is a hybrid non-steady-state puff/particle plume dispersion model, which integrates both puff and particle techniques to model an emission plume concurrently. It is also useful to predict the trajectory, dispersion, and concentration of pollutants from a point source, line, and area. HYSPLIT uses meteorological data to track the movement and concentration either forward or backward in the period and at regular intervals. The HYSPLIT itself is a well-established model where it possesses complex mathematical equations and algorithms behind it and involve various atmospheric processes, meteorological data, and numerical methods. The mathematical model in HYSPLIT involves a comprehensive set of equations that address the complexities of atmospheric dispersion, considering various factors influencing the movement and concentration of pollutants. In this study, the application of HYSPLIT to predict the agricultural area affected by air pollution in Kedah is the first time reported where it can be a pioneered study in the field of environmental research for the region.

2.2. Research Area

Kedah, which is located at the northernmost tip of the peninsula bordering Thailand, is Malaysia's eighth-largest state. It is also known as ‘The Rice Bowl’ of Malaysia (Liu, 2006). Most of the lands in Kedah are utilized for the agricultural sector which comprises rice cultivation, oil palm and rubber plantation. Kedah accounts for 40% of the nation’s rice production sector (Free Malaysia Today, 2022). **Figure 1** shows the location of Kedah in Malaysia.

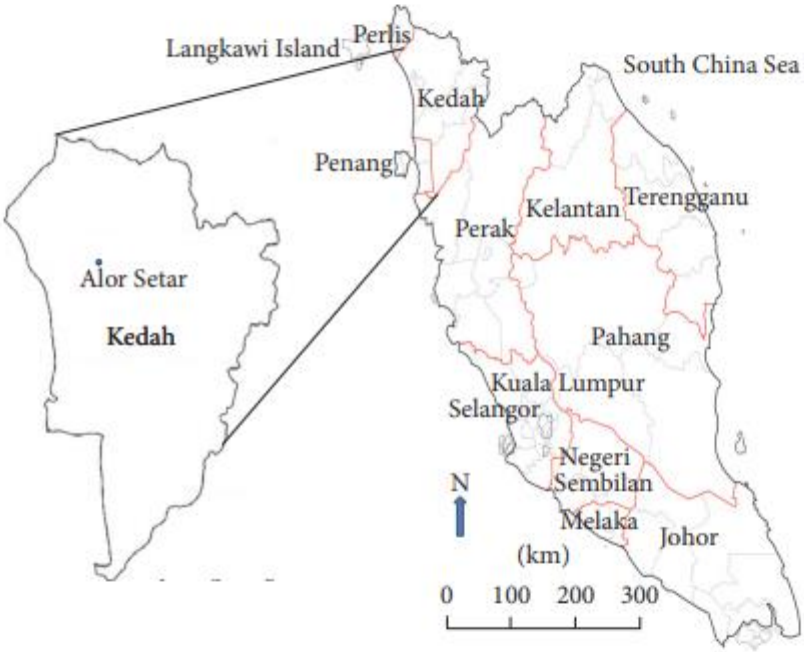

Figure 1. Location of the study area (Alzubaidi *et al.*, 2016)

2.3. Air Pollution Monitoring Stations in Kedah

There are currently four air quality monitoring stations situated within Kedah. **Table 2** shows the details of each monitoring stations.

Table 2. Locations of air quality monitoring stations in Kedah

Air Monitoring Stations	Representative names	Latitude	Longitude
Sekolah Kebangsan Bakar Arang	Sungai Petani	5°37'53.3"N	100°28'10.9"E
Kompleks Sukan Langkawi	Langkawi	6°19'53.4"N	99°51'30.2"E
Sekolah Menengah (A) Mergong	Alor Star	6°13'42.6"N	100°34'41.2"E
Kulim Hi-Tech Park Station	Kulim	5°22'48.6"N	100°32'57.2"E

2.4. Data from the Air Pollution Monitoring Station in Kedah

Table 3 shows the API's obtained from all four monitoring stations situated in Kedah. The values in the table indicate the highest API for each station from May 2019 to August 2019.

Table 3. Highest API from May 2019 to August 2019 for each monitoring station (Ynshung, 2022)

Station	API	Date
Sungai Petani	86	5/8/19
Alor Setar	79	5/8/19
Langkawi	72	5/8/19
Kulim	84	5/7/19

The API value from May to August 2019 in **Table 3** is chosen under certain conditions. First, monsoon seasons were considered when it comes to choosing the months in the year 2019. The concentration levels of the air pollutants were reported to be affected by the monsoon change (Kairan *et al.,* 2021). There are two types of monsoon seasons available in Malaysia which is southwest and northeast monsoon seasons. Southwest monsoon season occurs from May to September while northeast monsoon season takes place from November until March. During the southwestern monsoon, air pollutant concentration tends to be higher compare to the northeastern monsoon with mostly due to meteorological factors. Thus, this study only focuses on the API value from May to August 2019, considering the southwest monsoon season. The September month which is also within the southwest monsoon season was excluded in this study due to the forest fires occurred in Sumatra, Indonesia in September 2019 (Munthe *et al.*, 2019). The reason behind this is to avoid a sudden increase of particulate matter and other pollutants as this may produce uncertainties results in air quality research.

Figure 2 shows the air movement towards Kedah during the southwest season. The movement of wind towards Kedah plays a crucial role in obtaining accurate results. If the movement of wind is not towards the state, the receptor at the monitoring stations will not be able detect or receive the air pollutants, which eventually unable us to detect the source of emission. To further support this statement, previous study in the literature emphasized the level of concentration observed at Alor Setar exhibits a consistent rise in comparison to other monitoring stations throughout the southwest monsoon when conducting a study on the concentration parameter of wind movement (Satari *et al.*, 2015).

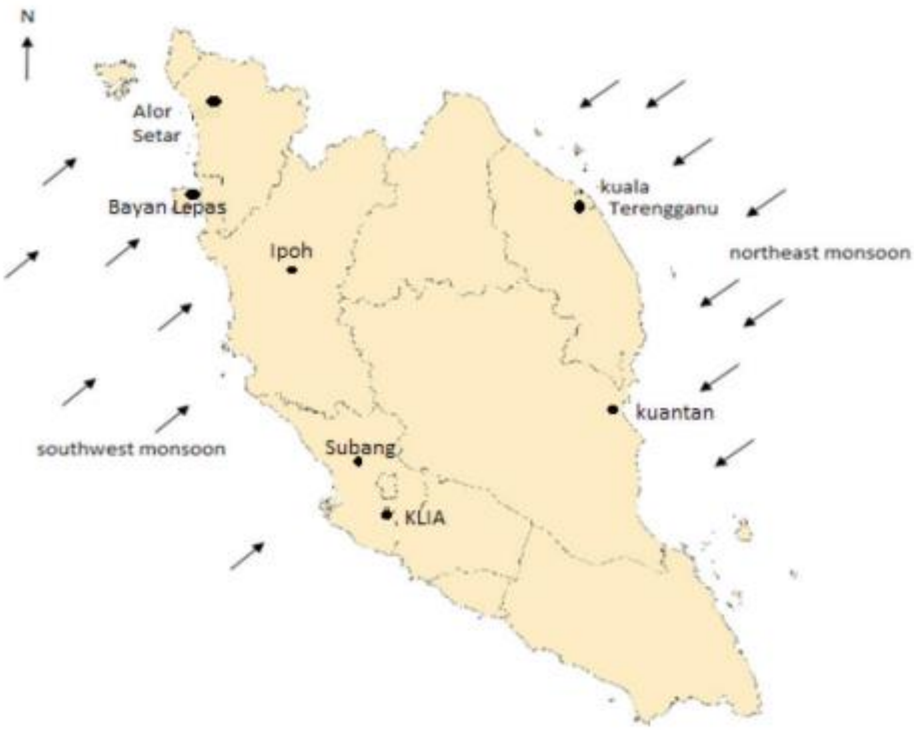

Figure 2. Monsoon season directions at Peninsular Malaysia (Satari *et al.*, 2015)

2.5. Inputs of Backward Trajectory Simulation

A backward trajectory simulation was performed to identify the source of emission. This method was conducted by tracing the movement of air particles backward in time from a specific location to identify their source regions. This simulation calculated the historical pathways of air masses arriving at a particular location. **Table 4** shows the inputs of a trajectory in HYSPLIT simulation.

Table 4. Inputs of backward trajectory simulation

Starting time	5/8/2019 (0600 UTC)
Coordinates of the air monitoring stations	5°37'53.3"N, 100°28'10.9"E 6°13'42.6"N 100°34'41.2"E 5°22'48.6"N 100°32'57.2"E
Total runtime	24 hours
Direction of the trajectory	Backward

From **Table 4**, inputs such as starting time of the backward trajectory, the starting location, which is the coordinates of the air monitoring station, total run time in hours, meteorological data file and the direction of the trajectory were required to run the simulation. The starting time comprises of year, month, day, and hour while the meteorological file can be obtained from the local meteorological department, NOAA (National Oceanic and Atmospheric) archive and forecast of model outputs.

2.6. Inputs of Forward Concentration Simulation

The forward concentration simulation was done to identify the agricultural area exposed by the pollutants. The simulation was performed by tracing the forward movement of air particles from a source region to a receptor location. This simulation predicts the location of the emitted pollutants disperse over time from a specific location. The inputs for a forward concentration are similar with the backward trajectory simulation except it has multiple set up tabs with additional inputs such as emission rate height of the monitoring station receptor, type of depositions and pollutant category. **Table 5** displays the inputs of the forward concentration setup tabs.

Table 5. Inputs of forward concentration simulation

Starting time	5/8/2019 (0600 UTC)
Starting Location	5°18'53.7"N 100°17'58.9"E
Total runtime	24 hours
Direction of the trajectory	Forward
Height of levels	10 m
Centre of latitude and longitude	5°18'53.7"N 100°17'58.9"E
Emission rate	225/hr
Hours of emission	24 hours
Release start	5/8/2019 (2pm)
Type of Pollutant	Particle

3. Results and Discussion

3.1. Backward Trajectory Results

Backward trajectory simulation is done based on two dates which are 5th August and 5th July in the year 2019. As seen from **Table 3**, the first three stations have the highest API on 5th August 2019 followed by Kulim monitoring station on 5th July 2019. These dates were chosen under two conditions. Firstly, the days were chosen based on the highest API reading recorded for each monitoring station. Secondly, the months where the wind movement is towards Kedah is taken into consideration which in this case would be southwest monsoon. Even though southwest season takes place from May to September, in this research September month is avoided although it has several high API readings. This is due to the haze problem that started during that month.

As per an article published in Sinar Harian News, the Malaysian Meteorological Department (MMD) indicated that the nation is likely to encounter haze until the middle of September. The cause of this phenomenon was attributed to forest fires that have taken place in Sumatra, Indonesia. According to the Deputy Director General of the MMD, Sumatra is situated in the southwestern region of Malaysia. The wind movement towards Malaysia is influenced by the geographic location of Sumatra and the extremely low wind pressure that exists in the South China Sea (Zainal *et al.*, 2021). Considering September would affect the results where the sources of haze is already known, unusual events in this month may not provide significant insights into the regular exposure of agricultural areas to pollution.

After running several simulations for different hours for both dates, the source of emission was identified, as shown in **Figure 3**. Each line is indicated with a colour code that represents its respective air monitoring station; green for Alor Setar Station, red is for Sungai Petani Station and Blue for Kulim Station. This backward trajectory simulation was finalized after analysing every single intersection of the lines. Each intersection has the potential of being the source of emission.

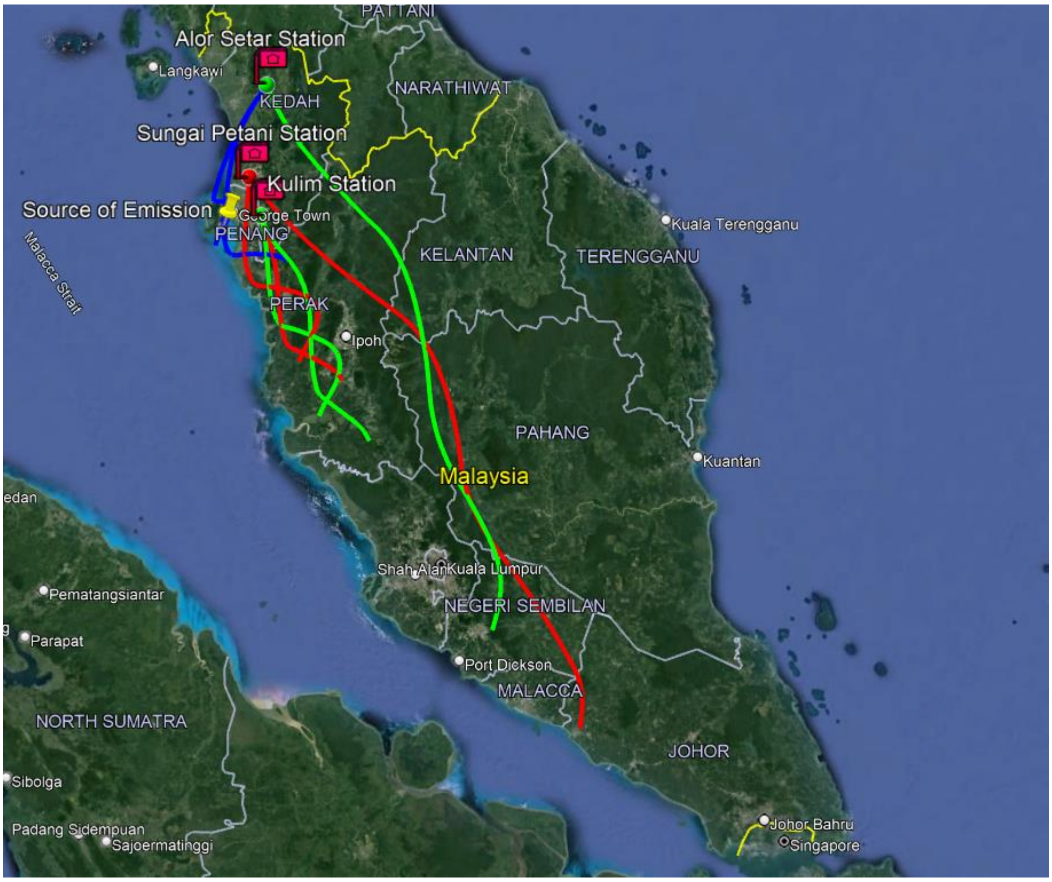

Figure 3. Backward trajectory map

Figure 4 displays the closer look of the source of emission. The backward trajectory led to the industrial zone situated at Bayan Lepas. It was concluded that this location has a high potential to be the source of emission compared to other locations due to the number of industries located around it such as metal manufacturing places, cement factory, waste transfer station, landfills, and power stations. The inclusion of the housing view and city name shown in **Figure 4** enhances readers' comprehension of the affected location. It is evident that the emission source impacts residential and industrial areas rather than the forest, suggesting potential implications for human health.

Previous study stated that PM_{10} is one of the major pollutants released from coal fired power plant apart from SO_2 and NO_x (Leh, 2016). PM_{10} is released in the form of dust and fly ash during the incomplete combustion of coal. Furthermore, metal manufacturing also known as metal fabrication involved several processes that emits PM_{10}. According to Strezov *et al.*, metal fabrication is known to produce a large amount of PM_{10} (Strezov *et al.*, 2021). This emission is generated during the various stages of metal and mineral processing such as grinding, crushing, sizing, the drying process, and calcining.

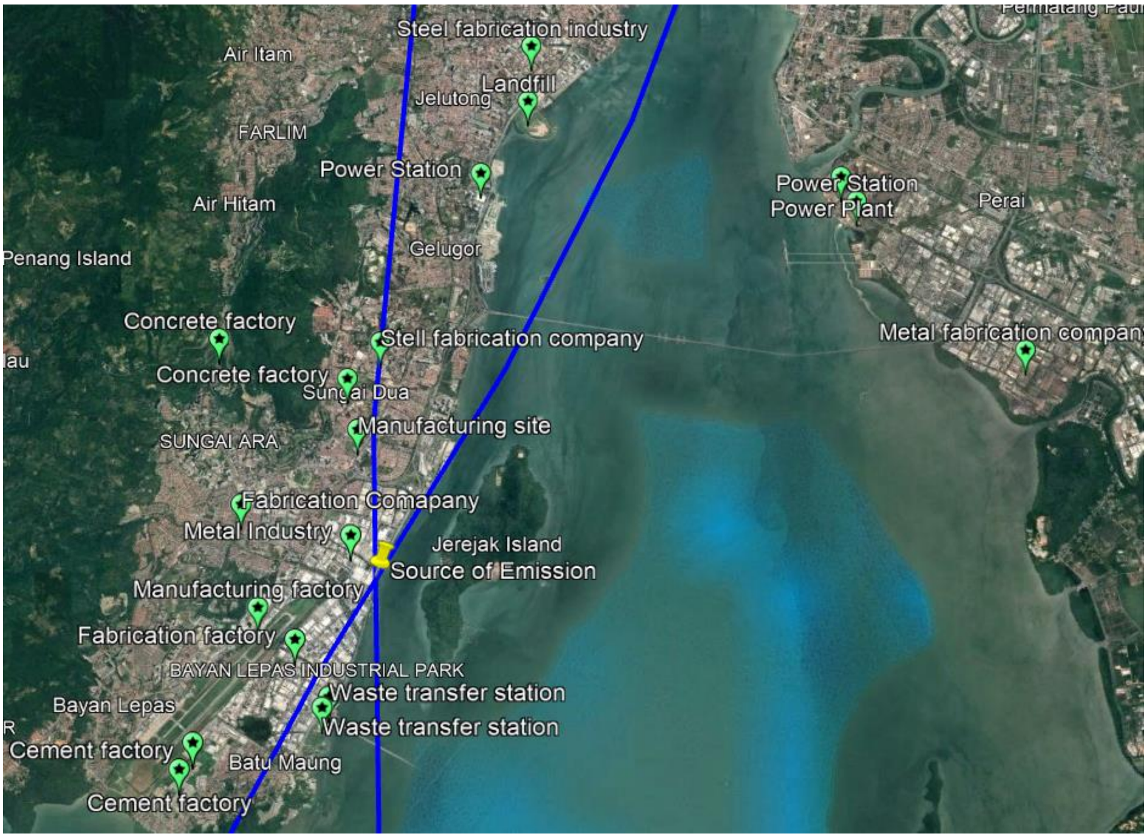

Figure 4. Source of emission

In addition, numerous global studies indicate that cement mills discharge a substantial number of pollutants into the air. Cement powder's PM_{10} is composed of mineral particles, sea spray, and secondary inorganic aerosols (Rovira *et al.*, 2018). The manufacturing of cement is widely recognized as the primary contributor to PM_{10} emissions, comprising approximately 40% of overall industrial emissions and 25-30% of total PM emissions. Apart from cement factories, waste transfer stations or landfills reports high concentration of PM_{10} regardless its role in controlling municipal waste (Firuza and Nather, 2011).

3.2. Forward Concentration Results

After identifying the source of emission, the coordinate of it is used to simulate a forward concentration map to analyse the areas exposed to air pollutants. The forward concentration was carried out on 5th August 2019 and the total runtime of the simulation is 24 hours. This is because the averaging period of PM_{10} is 24 hours (Department of Environment, 2019). The emission rate in the definition of pollutant tab was estimated using the data obtained from DOE.

As of December 2019, a total of 11,126 industrial sources were emitting air pollutants. From **Figure 5**, it can be noted that Penang has 1233 industrial sources which makes up around 11% of industrial sectors out of the whole nation. 17878 metric tonnes of PM_{10} were released by power stations and industries where Penang accounts 1966.58 metric tonnes which is equivalent to 224.35 kg/hr (Department of Environment, 2019).

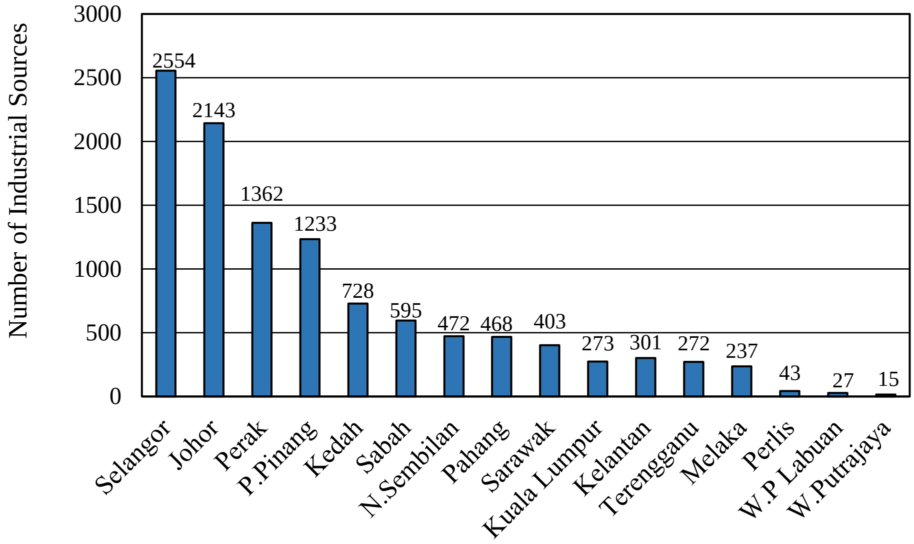

Figure 5. Industrial air pollution sources by state in year 2019 (Department of Environment, 2019)

From **Figure 6**, there are four different colours where it ranges from yellow to light blue which indicates severe to low concentration. Yellow colour denotes that the concentration level is really severe and as for dark blue colour it indicates that the region is exposed to high concentration of air pollutant. Moreover, green and light blue are considered to be moderate and low. It can be observed that there are six agricultural areas which includes paddy field and orchards that fall under the green and light blue region. This clearly indicates there are agricultural areas at Kedah that are being exposed to air pollutants. It can be concluded that the agricultural areas are within the safe zones as the concentration level is deemed to be low and moderate. Before performing the HYSPLIT simulation in Kedah region, the existing air monitoring station can only record the API reading within 1500 hectares where some affected areas were not included in the system. Based on the result obtained in this study, it enables the farmers to assess the potential impact of air pollution on crop health and productivity. Knowing that pollutant concentrations are within the safe zones, this can provide assurance regarding the suitability of the environment for farming activities especially as the largest rice producer in Malaysia.

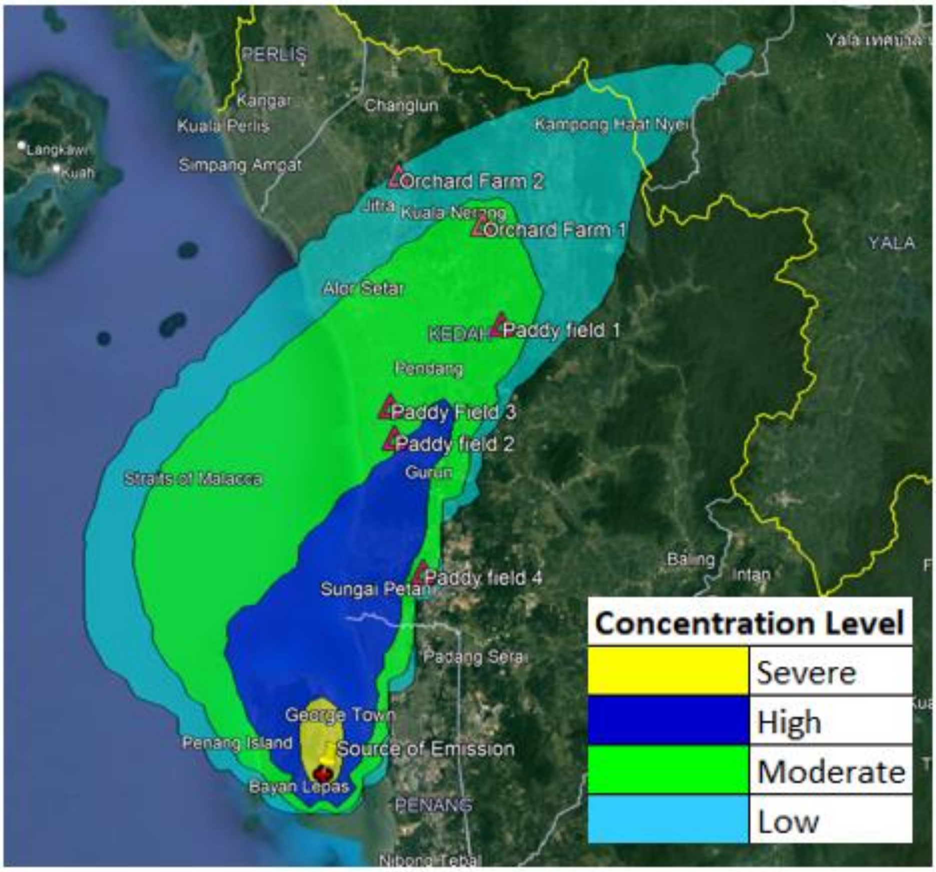

Figure 6. Forward concentration map

Similar studies were reported to predict pollution area using HYSPLIT model. Ma *et al.* performed HYSPLIT simulation to analyse the main transport channels and the potential sources of atmospheric pollutants in Shenyang City, China. The analysis results revealed on several affected pollution areas and identified main potential sources of pollutant (Ma *et al.*, 2019). Another simulation study using HYSPLIT model was conducted by Halima *et al.* on prediction of air pollution distribution pattern in Pasir Gudang Industrial Area, Johor, due to poor air quality incident that occurred in June 2019. The trajectory maps obtained from this study was able to predict potential areas affected by the air pollution (Halima *et al.*, 2023). Thus, it can be concluded that the application of HYSPLIT model as a prediction tools helps the local authorities to develop better standard operating procedure by serving the findings from this research work as a guideline in reducing air pollution impacts on the agricultural area.

4. Conclusion

Backward trajectory simulation and forward concentration simulation were conducted in this study to predict the coordinate of emission sources and the affected agricultural area in Kedah during southwest monsoon season in 2019. The analysis shows that the source of emission was located at Bayan Lepas. After analysing each of the intersection and the industries surrounding it, the industries that were mostly surrounded was metal fabrication companies, power stations, landfills, cement company and waste transfer stations which all emit PM_{10}. Based on the result obtained from the forward concentration map, six places were exposed to the air pollutant which includes paddy fields and orchards, and this could lead big threats like food security since air pollutants have a significant negative impact towards plant growth and crop productivity. All six regions are located within the state of Kedah and are subject to low to moderate levels of air pollution. Based on the available evidence, it can be inferred that the agricultural areas in question are operating within acceptable safety parameters.

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Credit Author Statement

Conceptualization and methodology, Kumarasamy, T., Chng, L.K., and Hamid, I.A.A.; software and validation, Kumarasamy, T., formal analysis, Kumarasamy, T.; investigation, Kumarasamy, T.; resources, Chng, L.K.; data curation, Kumarasamy, T. and Chng, L.K.; writing—original draft preparation, Kumarasamy, T., Chng, L.K., and Hamid, I.A.A.; writing—review and editing, Hamid, I.A.A.; visualization, Hamid, I.A.A.; supervision and project administration, Chng, L.K.

Conflicts of Interest

The authors declare no conflict of interest.

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